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Vertical gardening undergirds household food security: evidence from Nairobi's Kibera informal settlements

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Rapid urbanization in Nairobi has intensified food insecurity, especially in informal settlements like Kibera, where 85% of residents face chronic hunger. Vertical gardening has emerged as a grassroots solution to these challenges, offering a localized, space-efficient method for improving household food security. The study investigates how vertical gardening contributes to the four dimensions of food security—availability, access, utilization, and stability—while also exploring embedded gender dynamics. The study employed a multi-method qualitative design, including in-depth interviews, focus group discussions, unstructured observations, and key informant interviews. These approaches were used to unpack labor regimes, household experiences, and the perceived value of vertical gardening in Kibera's informal settlements. Vertical gardening was found to: Enhance availability through crop diversification and continuous production cycles, improve access by reducing reliance on market purchases and enabling surplus sales, support utilization via improved dietary diversity and safer food preparation and strengthen stability by buffering households against economic and climatic shocks. Households practicing vertical gardening reported greater resilience and nutritional security, with women playing a central role in garden maintenance and intra-household food distribution. Vertical gardening is not merely a survival strategy. It represents a transformative practice that fosters urban resilience, gender empowerment, and community solidarity. However, its scalability is constrained by insecure land tenure, limited water access, and inadequate institutional support. The paper calls for targeted investments in training, microfinance, and policy integration to embed vertical gardening within broader urban food system reforms.

KEYWORDS

vertical gardening, urban agriculture, urban food security, informal settlements, household nutrition

1 Introduction

Rapid urban growth in the 21st century driven by rural–urban migration, environmental pressures, and climate change has reshaped global demographics, with over 55% of the world's population now residing in cities, a figure projected to reach 68% by 2050 (UN-Habitat, 2022). This expansion, particularly across the Global South, has placed immense strain on food systems and deepened food insecurity in informal settlements, where infrastructure, governance, and economic opportunities remain inadequate (Aboulnaga et al., 2025). The Global Report on Food Crises (Global Network Against Food Crises, 2024) estimates that 282 million people faced acute food insecurity in 2023 an alarming increase of 24 million from the previous year. According to the Food and Agriculture Organization (FAO), food security exists when all people, at all times, have physical and economic access to sufficient, safe, and

nutritious food that meets their dietary needs and food preferences for an active and healthy life (Food and Agriculture Organization, 1996). This definition highlights the multidimensional nature of food security encompassing availability, access, utilization, and stability which are increasingly compromised in urban informal settlements due to systemic vulnerabilities.

The 2024, State of Food Security and Nutrition in the World (SOFI) report underscores that urbanization is reshaping agrifood systems across the rural–urban continuum, intensifying food insecurity and nutritional inequities, particularly in informal settlements. As urban poverty grows and traditional food transfer systems erode, healthy diets are becoming increasingly unaffordable and inaccessible for low-income populations. In response, the report advocates for territorial approaches that integrate localized, inclusive, and sustainable food production strategies. However, it cautions that without institutional support, infrastructure investment, and coherent policy frameworks, such innovations risk remaining survival strategies rather than transformative solutions to urban food insecurity.

In Kenya, urbanization exceeds 4% annually, with 28.5% of the population living in cities (World Bank Group, 2023). Nairobi's informal settlements, such as Kibera, epitomize this crisis: about 85% of residents are food insecure, relying on precarious livelihoods and volatile markets (Ayuya, 2024). Unlike rural food insecurity, which is often tied to agricultural productivity, urban food insecurity stems from income volatility, dependence on purchased food, and limited access to productive resources like land and water (Ayuya, 2024; Soma et al., 2022). Urban poor households spend up to 60% of their income on food, leaving them vulnerable to price shocks (Food and Agriculture Organization, 2023a; Food and Agriculture Organization, 2023b). This disparity underscores the need for context-specific interventions, such as urban agriculture, to bridge the gap between food supply and demand in slums (Vilar-Compte et al., 2021).

Several interlinked drivers, rapid demographic shifts, climate change, and economic volatility—are transforming urban food systems, especially in rapidly urbanizing contexts like Nairobi. As cities expand, population growth and rural–urban migration intensify pressure on food supply chains, infrastructure, and governance. The densification of urban spaces—particularly through informal settlement expansion—reduces available land for agriculture and complicates food distribution logistics. Simultaneously, climate change exacerbates these challenges by disrupting rainfall patterns, increasing temperatures, and triggering extreme weather events that threaten both urban and peri-urban food production. These environmental pressures heighten the vulnerability of urban poor populations, who already face precarious livelihoods and limited access to nutritious food (FAO et al., 2024; Anandhi et al., 2025).

Economic inequality and shifting consumption patterns further reshape urban food systems. In many cities, informal economies dominate, leaving households reliant on unstable incomes and exposed to volatile food prices. This economic fragility forces urban poor families to spend a disproportionate share of their income on food often up to 60% while limiting their ability to access healthy diets. As urban lifestyles evolve, there is a marked shift toward processed and convenience foods, contributing to a dual burden of malnutrition: undernutrition and rising rates of obesity and non-communicable diseases. These dietary transitions reflect broader systemic gaps in food governance, where urban food systems often fall between national agricultural policies and municipal mandates, resulting in fragmented planning and inadequate investment (Alemu and Grebitus, 2020; FAO et al., 2024).

The transformation has led to several notable outcomes, particularly in rapidly urbanizing regions. One of the most visible shifts is the increased consumption of processed and convenience foods, driven by changing lifestyles, time constraints, and the proliferation of informal food markets. This dietary transition has contributed to a dual burden of malnutrition, where undernutrition coexists with rising rates of obesity and non-communicable diseases (de Bruin et al., 2021). The demand for high-value and ultra-processed products is reshaping food environments, often at the expense of traditional, nutrient-rich diets, especially among low-income urban populations. Another critical outcome is the diminishing role of agricultural labor in urban and peri-urban areas. As cities expand, agricultural land is increasingly converted for housing and infrastructure, reducing opportunities for small-scale farming and displacing agricultural workers. This shift has weakened rural–urban food linkages and undermined traditional food transfer systems that once buffered urban households against market volatility (Stefanovic et al., 2020). Moreover, the shift in urban food systems has intensified market dependency and economic vulnerability. Urban poor households now rely heavily on purchased food, spending up to 60% of their income on food alone, which exposes them to price shocks and supply disruptions (FAO et al., 2024). This dependency is compounded by fragmented governance and inadequate infrastructure, which limit access to affordable, safe, and nutritious food. While innovations, technological advancements such as vertical gardening, hydroponics, and digital food platforms offer adaptive solutions to land scarcity and market exclusion, their impact remains constrained by systemic and structural barriers including insecure tenure, water scarcity, and limited institutional support (de Bruin et al., 2021). At the same time, grassroots movements and participatory planning initiatives are gaining traction, demonstrating the potential of inclusive governance to drive food system transformation. Examples like the Mukuru Special Planning Area in Nairobi highlight how community-led approaches can integrate food security into broader urban resilience strategies, paving the way for more equitable and sustainable urban food systems (Anandhi et al., 2025; Alemu and Grebitus, 2020).

Vertical gardening is the practice of cultivating crops in stacked containers, repurposed sacks, or hydroponic systems, which gained prominence in informal settlements as a means of overcoming extreme land constraints to grow vegetables and rare animals bridging the economic and food insecurity gap (Gallaher et al., 2013; Adegun et al., 2022).

In informal settlements like Kibera, where open spaces are virtually nonexistent, vertical gardens allow residents to grow food upwards rather than outwards, making them ideal for densely populated areas with little land. Residents have innovatively used old tires, plastic bottles, and burlap sacks to grow vegetables such as kale and spinach, thereby helping residents access fresh produce and reducing reliance on expensive market food (Ndunge, 2022). With the support of non-governmental organizations, hydroponic systems are progressively being introduced, further increasing the efficiency of food production in these limited spaces. These innovative approaches not only address food insecurity but also promote sustainable urban agriculture practices, self-sufficiency, and community empowerment in a resource-constrained environment (Odero, 2023).

These methods align with the broader principles of urban resilience, enabling households to produce food in marginal environments while conserving water and minimizing soil use (Lal, 2020). Research indicates that vertical gardening contributes to food security across multiple dimensions: it enhances availability by diversifying household diets, improves accessibility by reducing dependence on distant markets, increases affordability through surplus sales, and strengthens stability by buffering against economic and climatic shocks (Gallaher et al., 2013; Swanepoel and Van Niekerk, 2021).

However, the effectiveness of vertical gardening is not without controversy. While some studies highlight its potential to improve nutrition and livelihoods (Premalatha et al., 2024), others caution that its impact is often modest and highly context-dependent (Swanepoel et al., 2021). Structural barriers such as insecure land tenure, contaminated water sources, and limited institutional support frequently constrain scalability (Kimani-Murage et al., 2014). For instance, in Kibera, many vertical gardeners rely on polluted runoff or costly piped water for irrigation, compromising crop safety and yields. Although innovations like low-cost greywater filtration and rainwater harvesting have been proposed, their adoption remains limited due to financial and technical constraints (Food and Agriculture Organization, 2023a; Food and Agriculture Organization, 2023b). These concerns are echoed in a recent realist review of household gardening interventions in LMICs, which found that effectiveness hinges on specific intervention-context-mechanism-outcome (ICMO) configurations. The review identified three key pathways; production, income, and knowledge and emphasized that gardening programs must account for social, environmental, and motivational factors to achieve sustained impact (Flores et al., 2025). Without addressing these systemic challenges, vertical gardening risks remaining a survival strategy rather than a transformative solution to urban food insecurity.

This study explores how vertical gardening systems contribute to household food security in Kibera through the interconnected dimensions of food availability, accessibility, utilization, and stability. It further examines the broader implications for building resilient and sustainable food systems in informal settlements.

2 Materials and methods

2.1 Study site

This study was conducted in Kibera, Nairobi County, one of the largest informal settlements in Kenya and sub-Saharan Africa, spanning approximately 12.1 square kilometers [Kenya National Bureau of Statistics (KNBS), 2019]. Home to an estimated 185,777 residents across 61,690 households, Kibera is characterized by high population density, fragile infrastructure, and pervasive economic deprivation. Most households reside in makeshift shelters constructed from mud, timber, and corrugated metal sheets, often lacking reliable access to clean water, sanitation, or electricity (Gcwabe et al., 2021). The majority of residents earn livelihoods through informal, low-wage activities such as street vending, waste picking, and casual construction work, contributing to widespread income instability (Ayuya, 2024; World Bank Group, 2023). Food access in Kibera is especially volatile; many households depend on small, expensive purchases from kiosks and local markets, where prices fluctuate sharply during droughts, political unrest, or economic shocks (Battersby and Watson, 2018). Nairobi County data from the 2022 Kenya Demographic and Health Survey (KDHS) shows a wasting prevalence of 2.5% among children under five—lower than the national average of 5% while national stunting rates stand at 26%. In Kibera, child nutrition indicators reveal significant vulnerabilities: a study among children aged 6–23 months reported stunting at 25.3%, underweight at 8.6%, and wasting at 4.0%, with stunting disproportionately affecting older children and boys. Additionally, 64.1% of children had experienced illness in the preceding two weeks, yet only 26% received medical consultation within 24 h, underscoring the compounding effects of poor nutrition, morbidity, and limited healthcare access. Kenya National Bureau of Statistics (KNBS) (2023) data reveal persistent disparities in food access and nutritional outcomes between male- and female-headed households in urban areas. Three sub-villages, Lindi, Makina, and Laini Saba, were purposively selected for this study. These sites represent Kibera's socio-economic and spatial heterogeneity and demonstrate active engagement in vertical gardening practices (see Figures 1, 2).

2.2 Research design

This study adopted a phenomenological qualitative approach to explore the lived experiences of households practicing vertical gardening in Kibera's informal settlements, with a focus on its perceived impact on household food security. Phenomenology, as defined by Creswell and Creswell (2017), seeks to understand the essence of a phenomenon by capturing how individuals experience it in their own words and contexts. In this case, the approach was particularly suited to uncovering the personal struggles, adaptive strategies, and nuanced perceptions of residents navigating chronic food insecurity within a fragile urban environment. Phenomenology prioritizes depth over breadth, allowing for a rich, empathetic understanding of how vertical gardening is experienced as both a survival strategy and a form of agency. The decision to use phenomenology was grounded in the need to center marginalized household voices, whose perspectives are often underrepresented in urban food systems discourse. Through fifty (50) indepth interviews with male and female heads of households, and four (4) focus group discussions, the study captured both individual and collective narratives around food availability, access, utilization, stability, environmental constraints, and the symbolic and practical value of vertical gardening. These methods, supported by Kvale and Brinkmann (2009), are particularly effective in exploring social relations, emotional landscapes, and community dynamics all of which are critical to understanding how food security interventions are received and sustained in informal settlements. To complement these perspectives, key informant interviews were conducted with local NGO staff and community leaders to provide contextual insights into programmatic support, policy constraints, and institutional dynamics surrounding urban agriculture. Direct observations of vertical gardening setups, ranging from sack gardens to hydroponic systems were also undertaken to document physical layouts, resource use, and environmental conditions. These observations enriched the data by grounding participant narratives in tangible practices and spatial realities. Thematic analysis was employed to distill recurring patterns and meanings from the data, ensuring that findings were grounded in participants' lived realities rather than imposed frameworks.

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FIGURE 1
Women gardeners planting vegetables on a vertical garden.



FIGURE 2
Vegetable harvesting from the vertical garden.

2.3 Sampling

The study utilized purposive sampling to select three villages (Lindi, Makina, and Laini Saba) from Kibera's thirteen sub-villages. These locations were specifically chosen because they represent the socio-economic diversity of Kibera reflecting age, household type, livelihood strategies while demonstrating active engagement in vertical gardening practices. Lindi was selected for its high population density and proximity to markets, Makina for its mixed livelihood strategies, and Laini Saba for its relatively lower density and greater available space for gardening activities. To identify participants with substantive engagement in vertical gardening, the research team collaborated with Community-Based Organizations (CBOs), agricultural support groups, and local elders active in the target settlements. Households were eligible if they had at least six months of vertical gardening experience, a threshold chosen to ensure participants had engaged long enough to reflect on both the challenges and benefits of the practice. These groups provided referrals based on their direct engagement with community members involved in urban gardening initiatives. The referral process was informal but strategic, relying on community-based organizations (CBOs) with firsthand knowledge of households practicing vertical gardening, particularly those recognized for consistent cultivation or involvement in training sessions. While this method improved trust and access within the community, it also introduced potential selection bias in reaching certain demographic groups by favoring households with strong social ties or visibility within organized groups and inadvertently excluded less socially connected individuals. Timing further influenced participation, with some residents unavailable due to livelihood obligations. These constraints, while reflective of the realities of fieldwork in resource-constrained urban environments, were mitigated through rapport-building sessions, flexible scheduling, and engagement with local leaders to maximize inclusivity and community ownership of the research process. Additionally, triangulation through spot visits and snowball referrals initiated by initial participants helped mitigate potential bias. Nevertheless, these constraints, coupled with the absence of a centralized household registry, limited the randomness of the sample and reduced representativeness across demographic subgroups. These limitations are acknowledged as part of the contextual realities of conducting fieldwork in informal settlements.

2.4 Data collection

A total of 50 IDIs (25 women and 25 men) were conducted at participants' homes and garden sites, utilizing semi-structured questionnaires. Participants were identified through referrals from local farmer groups, an approach that proved effective given the close-knit nature of gardening communities and the challenges of random sampling in informal settlements. These interviews provided rich, firsthand narratives of individuals' lived experiences with urban vertical gardening (see Figure 3).

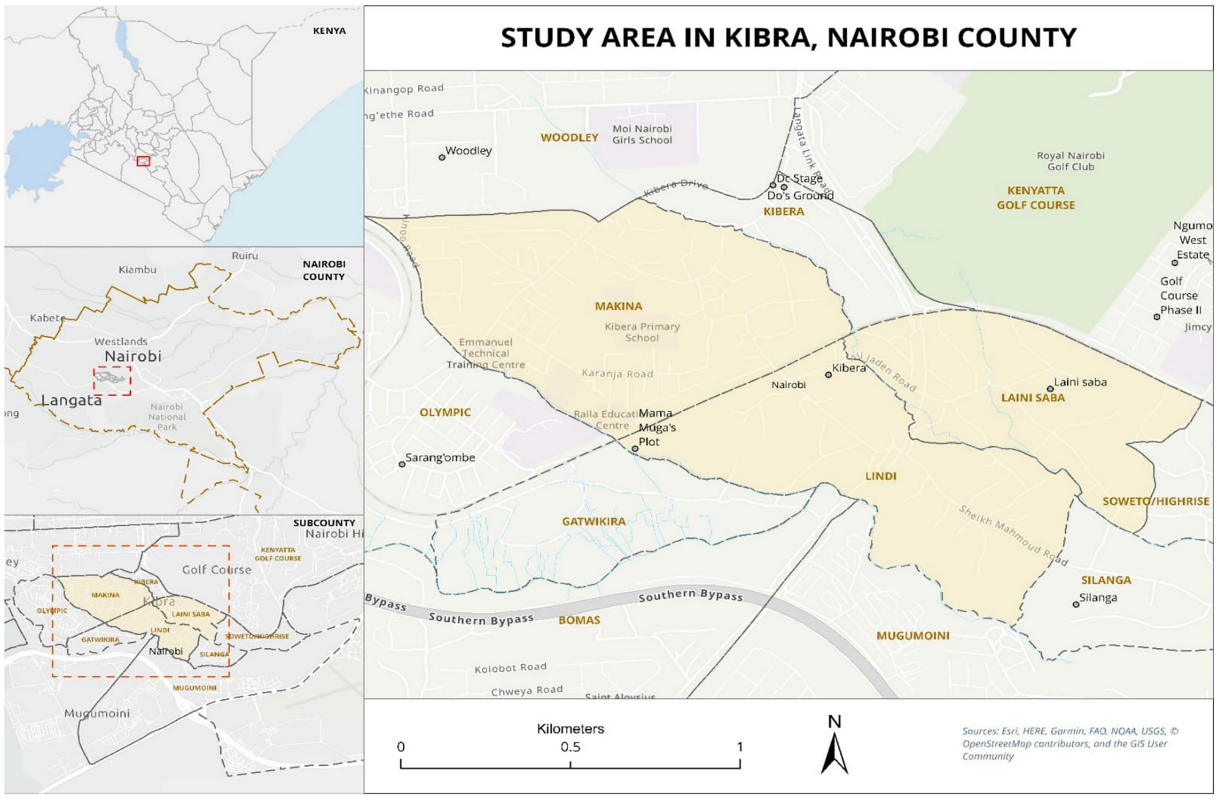


FIGURE 3
The map of Kibera slums in Nairobi, Kenya.

To capture broader community-level dynamics, four FGDs were held in which two were exclusively with women and two with mixed-gender participants. This allowed for deeper engagement and shared reflections on collective gardening practices, challenges, and social integration. Additionally, eight KIIs were conducted with local leaders, agricultural extension officers, and community-based organization (CBO) representatives to gain institutional perspectives on policy environments, support systems, and barriers to implementation.

Observations complemented these verbal accounts by providing tangible insights into gardening practices, spatial arrangements, and the environmental conditions influencing participants' experiences. Complementing these methods, systematic observations were conducted at various gardening sites, including individual household plots and community-managed spaces. The researcher documented farming techniques, work patterns, and physical constraints, providing contextual data to verify and enrich interview findings. This multi-method approach enabled triangulation of data across different sources and scales, from individual narratives to community norms and institutional frameworks, ensuring a comprehensive understanding of vertical gardening's role in household food security.

This phenomenological approach enabled the study to foreground personal and communal narratives, enriching the understanding of urban vertical gardening as a lived and socially embedded practice.

2.5 Data analysis

Following Braun and Clarke's (2006) thematic analysis framework, the data analysis proceeded through five phases: familiarization, transcription, coding, theme development, and refinement. All audio recordings were transcribed verbatim to capture the nuances and tone of participants' narratives. Transcripts were initially reviewed and organized in Microsoft Word, then imported into NVivo for systematic coding. Portions of dialogue in Swahili were professionally translated into English to preserve contextual depth and linguistic accuracy (Krippendorff, 2018). Despite these efforts, translation carried inherent limitations. Some culturally embedded phrases, idioms, and gendered metaphors in Swahili did not map directly onto English. To mitigate this risk, iterative translation reviews were conducted, employed back-translation on sensitive segments, and annotated ambiguous expressions to preserve meaning.

Meaning-making emerged through iterative reading, allowing both predefined theoretical concepts and emergent patterns to surface organically. Thematic development began with open coding to segment data into distinct units of meaning, followed by axial coding to establish relationships between categories (Corbin and Strauss, 2008). Given the multi-method design comprising in-depth interviews (IDIs), focus group discussions (FGDs), and key informant interviews (KIIs) triangulation was employed to enhance analytical rigor. Divergences between data sources were resolved through thematic cross-comparison. For example, while KIIs often portrayed NGO-led hydroponic farming as widely adopted, IDIs with household respondents revealed minimal uptake, citing cost and technical constraints. Such discrepancies were reconciled by privileging lived experiences drawn from IDIs and FGDs, while positioning institutional narratives as programmatic or aspirational perspectives. FGDs provided additional validation or challenge to individual and institutional claims, strengthening interpretive consistency.

3 Results

3.1 Demographic characteristics of the participants

The study engaged a total of 89 participants across three villages; Lindi, Makina, and Laini Saba through a mix of in-depth interviews (IDIs), focus group discussions (FGDs), and key informant interviews (KIIs). IDIs was the primary method of data collection across all sites, followed by FGDs and a smaller number of KIIs. The gender distribution was relatively balanced, with a slight female majority (49 females and 40 males). Age representation varied by village; Lindi had a high proportion of youth (15–34) and elders (60+), reflecting its profile of high informal work, economic instability, and limited support systems; Makina was dominated by adults (35–59), with more stable livelihoods rooted in diverse farming and moderate income security; while Laini Saba showed a more balanced age spread, characterized by mixed income sources and high vulnerability. Overall, the demographic composition reflects diverse gender and age perspectives shaped by varying degrees of economic stability and livelihood types across the three communities. The IDIs, FGD and KIIs sessions generated data on the contribution of vertical gardening to household food security, focusing on four dimensions of food security: availability, access, utilization and stability (see Table 1).

3.2 Food availability

According to Food and Agriculture Organization (2008), food availability refers to the physical presence of sufficient quantities of food, whether produced locally, imported, or distributed through markets and aid channels. In Kibera, residents often rely on market-sourced vegetables, which are frequently costly and inconsistent in quality. Vertical gardening presents a sustainable alternative by enabling households to cultivate nutritious vegetables at home, thereby ensuring a more reliable supply of healthy foods. This home-based production reduces dependence on expensive market options while enhancing both food availability and dietary consistency.

> *"It was a must that I had to buy vegetables daily. And I could spend 60 shillings daily on buying them. Right now, I do not buy vegetables; I only buy onions and tomatoes."* (KE IDI 01 female)

> *"When there is drought people struggle, they do not get vegetables. A person eats ugali with salt, strong tea."* (KE IDI 12 male)

> *"Limited space means most of the crops grown are vegetables, and individuals grow for domestic and commercial purposes. Mostly sukuma and spinach. Others grow exotic vegetables like terere, amaranth."* (KE KII 04 male)

> *"It has helped because we no longer have the burden of buying vegetables every now. We normally share these vegetables."* (KE IDI 01 female)

Vertical gardening enables households to grow a sufficient quantity of food by maximizing available space and optimizing resource use. By cultivating vegetables in stacked sacks or containers, families in Kibera

TABLE 1 Demographic characteristics of study participants.

		Sex			Age			Income
Village	Interview type	Male	Female	Total	Youth (15–34)	Adults (35–59)	Elders (60+)	Income profile by village
Lindi	IDIs	7	11	18	High	Moderate	Low	High informal work, high instability, low support
	FGDs	8	8	16	High	Moderate	High	High informal work, high instability, low support
	KIIs	2	1	3	Moderate	High	Low	Diverse farming, moderate income stability
Makina	IDIs	6	10	16	Moderate	High	Low	Diverse farming, moderate income stability
	FGDs	4	4	8	Moderate	High	Low	Diverse farming, moderate income stability
	KIIs	1	1	2	Moderate	High	Low	Diverse farming, moderate income stability
Laini Saba	IDIs	7	9	16	Moderate	High	Moderate	Mixed sources, high vulnerability
	FGDs	4	4	8	Moderate	High	Moderate	Mixed sources, high vulnerability
	KIIs	1	1	2	Moderate	High	Moderate	Mixed sources, high vulnerability
Total	-	40	49	**89**	-	-	-	-

*Total number of respondents.

informal settlement grow a variety of crops even in small areas, ensuring a steady food supply throughout the year.

> *It's urban farming and it conserves space. You can plant a lot in a small space because it grows vertically and is somehow stair cased and spiral.* (KE IDI 19 male)

> *I have grown managu in tires and it's doing very well and I have also grown kales and it's doing well because tires store water so it does not lose water like tins.* (KE IDI 12 male)

In household farming, both men and women actively contribute to production, but women often play a pivotal role in maintaining gardens, ensuring a consistent supply of vegetables like sukuma wiki, spinach, and managu. Their daily involvement in planting, watering, and harvesting fosters a steady yield, crucial for resilient food system that supports long-term nutrition and well-being.

> *"More skilled in vertical gardening are women who spend most of their time in the gardens. They really want it to work for them."* (KE KII06 male)

> *"I grow all types of traditional vegetables. I grow all types of pepper. I also grow bananas."* (KE IDI 49 female)

> *Nutrition, they only grow hyper crops which are nutritious.* (KE KII01 male)

Furthermore, vertical gardening significantly enriches dietary diversity by enabling the cultivation of different crops simultaneously. Households integrate leafy greens, herbs, and other nutritious plants into their meals, improving overall health outcomes.

> *"It has increased because you can take this as a piece of land, and you put a sack and plant there your crops all round, and it will produce more."* (KE IDI 04 male)

Moreover, vertical gardening allowed for the cultivation of crops during periods of market shortages or financial hardship. When external sources of food were inaccessible due to high prices or market disruptions, these homegrown gardens served as an essential buffer against food insecurity.

> *Some people come here and borrow us vegetables but they do not pay and we understand them. If they say they will come back, you just know they do not have but they will not say that they do not have.* (KE IDI 19 male)

3.3 Vertical gardens enhance household access to food

According to the Food and Agriculture Organization (2008), food access is achieved when individuals and households have adequate resources to obtain appropriate food for a nutritious diet. In informal settlements, food accessibility is shaped not only by proximity but also by affordability, consistency of supply and income levels. Vertical gardening enhanced household access to fresh produce by reducing the reliance on daily purchases from local markets, described as financially burdensome and unaffordable for low income families.

> *"When there are plenty of vegetables in the farms, it is cheaper for people to buy as opposed to when there are small quantities. As for me, I have realized the change in that I cannot lack vegetables for consumption."* (KE IDI 45 female)

Participants highlighted the economic relief provided by growing their vegetables, securing a more reliable and cost-effective food source and further enabled them to reallocate scarce resources to other necessities such as cooking fuel, paying school fee or meeting the medical bills.

> *Families cannot sleep hungry, saving on the cost that could have been spent in buying vegetables.* (KE KII-5 male)

> *"Farming has been of benefit nowadays because you get vegetables, onions, and tomatoes here; you only have to look for flour and fuel for cooking."* (KE FGD 02 male)

Vertical gardening in Kibera's informal settlement has proven to be a game-changer in enhancing food access, especially for local vegetable vendors. This approach allows vendors to source produce directly from nearby gardens, reducing their reliance on external suppliers who may charge additional fees for transportation or face supply deficit. As a result, vendors can offer fresh produce at competitive prices, benefitting both themselves and the consumers.

> *For women who sell the vegetables, the distance is greatly reduced, going to the market and also the cost is relatively reduced. They are able to save on it.* (KE IDI 02 male)

Vertical gardens also expanded accessibility through intra-household and community sharing practices. In some cases, households with multiple sacks or high yields provided vegetables to neighbours or relatives, promoting localized forms of food access that bypassed the commercial systems. These informal distribution mechanisms played a critical role in mitigating food insecurity across extended social networks, particularly during times of financial distress.

> *"We no longer have the burden of buying vegetables every now, we normally share these vegetables."* (KE female IDI 01)

Food access is also a factor of household income. Majority of the Kibera population rely on informal economy (casual work and small businesses) for their livelihoods. As a result of unpredictable income, escalating food prices, irregular meals, or going to bed without food, is the norm for the population living in informal settlements.

> *"I have slept hungry so many times and also saw people who have slept hungry"* (KE IDI 49 female)
>
> *"90 percent of people living here do not get all the 3 meals in a day. Most people take one meal a day. There are children who take only a meal a day."* (KE FGD 02 male)

Through the sale of surplus, gardeners noted improved income enabling them to purchase other food items for the household.

> *I grow sukuma wiki, kunde. You see how it is. Sometimes we sell it and it even helps us in our kiosks, where I sell.* (KE IDI 48 female)

The ability of households to grow and access food within their immediate environment thus emerged as a key mechanism for improving food accessibility in constrained urban settings. The gendered structure of this system where women-maintained gardens and determined household food use further highlighted the central role of women in securing daily access to nutritious food.

> *If you go to the market and you do not get the vegetables but you can use the ones in your farm.* (*KE* IDI 03 male)

3.4 Vertical gardens improve food utilization for households

Food utilization refers to the body's ability to effectively use the nutrients in food, which depends on how food is prepared, stored, and metabolized to meet physiological needs (Food and Agriculture Organization, 2006). In Kibera, vertical gardening has significantly improved food utilization by increasing access to fresh, home-grown vegetables and enabling households to make more efficient use of limited resources. Residents report that cultivating food at home has reduced their reliance on market-sourced vegetables, which are often costly and inconsistent in quality.

> "*It was a must that I had to buy vegetables daily. And I could spend 60 shillings daily on buying them. Right now, I do not buy vegetables; I only buy onions and tomatoes.*" (KE IDI 01 female)

While subsistence remains the primary driver, vertical gardening offers additional economic benefits for urban households. Several families generate supplementary income by selling surplus produce, which helps cover the cost of non-cultivable essentials like maize flour, cooking oil, fish, or eggs boosting dietary diversity. Some participants also supplied vegetables to schools or nearby kiosks, demonstrating a modest expansion into commercial outlets. Worth noting that men controls the decisions over income use.

> *"When there is plenty of food, we supply to schools, hotels, hospitals, and to the surrounding."* (KE IDI 49 female)
>
> *"If I get money, I take it to my husband and he decides what we do. Sometimes I suggest things, but he says we'll talk later."* (KE IDI 19 female)
>
> *"Even when I sell vegetables, the money is not mine alone. My husband tells me how we will use it."* (KE FGD 06 female)

Vertical gardens improve affordability beyond monetary savings, addressing the non-acquisition dimension by offering consistent access to fresh vegetables amid rising market prices and unreliable food supply chains. Households report reduced dependency on external sources, especially during economic downturns and supply disruptions:

> *"The changes are that when there are no vegetables in the market you can use the ones in your small garden."* (KE IDI 03 male)
>
> *"I used to buy vegetables daily for 60 shillings. Now I grow them, and only buy onions and tomatoes. I can save that 50 bob or buy eggs."* (KE IDI 01 female)

Some farmers also noted that consuming their produce gave them confidence in food safety, as they could avoid market vegetables potentially contaminated with pesticides or polluted irrigation water. The perception of safety and cleanliness reinforced the value of home-grown vegetables over those sourced from urban markets.

> *"It has helped us with nutrition by eating vegetables that are planted in a clean place."* (KE FGD 01 male)

Utilization is further reinforced through cost-efficient cultivation methods. Recycled containers, minimal pesticide use, and organic composting reduce input costs, while harvesting on demand prevents spoilage and food waste eliminating the need for costly storage.

> *"Diseases and pesticides are not that common, as we use local alternatives."* (KE IDI 02 male)

> *"We use plastic containers, and clients love fresh kales straight from them."* (KE IDI 12 male)

Moreover, vertical gardening promotes health-related utilization by improving dietary quality and reducing medical expenses tied to poor nutrition. Fresh, home-grown vegetables like kale, spinach, and tomatoes support immunity and reduce reliance on processed foods.

> "*Financial aspects of selling surplus improve overall well-being.*" (KE KII 01 male)

> *"I got fresh vegetables from my farm and knew how to keep them healthy."* (KE IDI 05 female)

These practices contribute to improved dietary diversity and reduce the risk of food-related stress, especially during economic or climatic shocks. As one respondent put it, "*We allow community members to harvest a few vegetables for cooking so that they do not sleep hungry*" KE FGD 01 (male) highlighting the communal and nutritional value of vertical gardening in a densely populated informal settlement.

3.5 Stability of food throughout the seasons

Food and Agriculture Organization (2006) defines food stability as consistency of food availability and access with no disruption by external shocks or seasonal fluctuations as a result of economic, climate or environmental degradation. Food stability in Kibera's informal settlement is influenced by multiple interrelated factors, making access to nutritious and affordable meals a complex challenge. One of the primary variables affecting food security is low wages among residents, most of whom rely on informal employment. Many jobs within Kibera are inconsistent, with individuals earning meager wages from casual labor, small-scale trading, or domestic work.

> *"Unemployment levels are going high, and the population is growing so many people are involving themselves mostly with jua-kali jobs and small businesses"* (KE FGD 01 male)

> *Many people living in Kibera are doing informal jobs. That is their main source of income.* (KE FGD 01 male)

Another major factor is minimal agricultural production within the settlement, largely due to limited land availability. Unlike rural areas where farming can be done on expansive plots, Kibera's dense, informal housing structures leave little room for conventional agriculture.

Vertical gardening plays a crucial role in ensuring food stability across different seasons offering an adaptable system that allows crops to be grown year-round within limited spaces. It therefore maintains a steady supply of vegetables even during dry seasons or periods of extreme weather and ensures food security, reducing the risks associated with seasonal shortages and inflated market prices.

> *"When there was drought, there were people who came to train us on how to do farming. Even when there is war or drought, we are able to have food."* (KE IDI 08 female)

Vertical gardening supports food stability by promoting self-sufficiency among residents in informal settlements. Instead of relying on distant farms or expensive imports, gardeners cultivate their own produce close to their homes, reducing dependence on fluctuating market conditions. This decentralized food production model minimizes logistical challenges, allowing families to harvest fresh vegetables when needed rather than stocking up on overpriced or less nutritious alternatives. The reduced reliance on external suppliers also ensures that food remains affordable throughout the year, preventing scarcity-induced price hikes that often burden low-income urban populations.

> *"It has helped people to access food, and it has reduced the chances lacking food."* (KE IDI 41 female)

The stability of food systems in Kibera was further supported by vertical gardening practices, which enabled households to maintain a consistent source of fresh vegetables, even during periods of market instability or external shocks. Unlike market-dependent households, which are vulnerable to price fluctuations and supply chain disruptions, those who engaged in urban farming could maintain a steady supply of vegetables. This stability is particularly critical in informal settlements, where external shocks such as political unrest, flooding, or unemployment can abruptly disrupt food access.

> *"Urban area people should embrace farming because it is not only for the rural area. With a small space and training, we can plant vegetables for consumption at home so that we do not sleep hungry."* (KE FGD 01 male)

> *"It is a sustainable food system that should be considered in urban planning and slum upgrading. Each household to have space for gardening, and reduce food wastage."* (KE KII06 male)

Beyond economic and logistical advantages, vertical gardening enhances sustainability by fostering a culture of urban farming and collective resilience. When residents engage in vertical gardening practices, they contribute to a greener, more productive urban landscape, reinforcing community-driven food security efforts.

> "*The benefits here is staying in the group and farm and everybody to plant on their part. When we get the harvest, we put it together and get to take it to the market. Others we consume it at home*" (KE IDI 48 female)

> *"We help each other in different ways. The first thing is through farming that helps us get vegetables for food. Another way is through lending each other money when one of us needs"* (KE FGD 01 male)

Additionally, these gardens provide an opportunity for skill development and agricultural education, enabling more people to adopt long-term strategies for food cultivation. By integrating sustainable growing techniques and maximizing limited urban spaces, informal settlements can achieve continuous food stability, ensuring

that households have access to nutritious produce regardless of seasonal fluctuations.

> *"When we began, we were taught how to plant vegetables, to begin a Sacco that will support us in school and our business too and we saw that it could have good benefits."* (KE FGD 04 female)
>
> *Hydroponic is very versatile for urban farming. People do not need to fear the technology. Miscommunication on Agriculture and the role of biotechnology in food security remains a challenge.* (KEKII01 male)
>
> *"They have supported us fully in greenhouse farming although it is an asset-based loan. They brought us urban farming that is different from the local farming that we were previously doing."* (KE FGD 01 male)
>
> *"Another challenge is water. Sometimes it is dry, which affects the vegetables."* (KE FGD 01 male)

Although shifts toward more collaborative gender roles are emerging, systemic change requires targeted interventions including microfinance for women, secure land rights, and gender-sensitive agricultural policies to unlock vertical gardening's potential as a tool for equitable food security.

In Kibera's informal settlements, tenure insecurity is pervasive but women face heightened vulnerability due to exclusion from formal ownership and reliance on informal arrangements. Many cultivate vertical gardens on borrowed plots, shared compounds, or verandahs, all subject to eviction or repurposing without notice. Male intermediaries such as landlords, youth group leaders, or chiefs—often control access to land, limiting women's autonomy in farming decisions and exposing them to social gatekeeping.

> *"Getting space is a problem… We had to shift from the large piece of land because somebody had bought it."* (KE IDI 02 male)
>
> *"It is not our land… We are not sure if we will be chased out."* (KE IDI 43 female)
>
> *"If the landowner decides to build, I will have to move."* (KE IDI 44 female)

These precarious arrangements deter long-term investment, innovation, and training uptake essential components for scalability in urban agriculture.

> *"The land belonged to no one… We asked the chief for permission to farm."* (KE IDI 05 female)
>
> *"The space is very small… If we had enough land, everyone could farm on their own."* (KE FGD 04 female)

Water access equally emerged as a critical yet unevenly distributed resource, with gender playing a key role in burden-sharing. Women bear the cost of daily water purchases, often spending KES 20 per jerrycan during shortages diverting funds from other farming needs. Manual watering typically done by women consumes significant time, reducing participation in farmer groups or training activities that support scale and sustainability.

> *"Water is an issue… Untreated water affects vegetables."* (KE FGD 04 female)
>
> *"Water is the first thing… I fetch it and then weed by hand."* (KE IDI 05 female)
>
> *"I water the plants… then feed the chickens and clean the house."* (KE IDI 03 male)

Vertical gardening and hydroponics as a pathway to food security is constrained by limited access to affordable agricultural technologies. While innovations such as solar irrigation pumps, filtration systems, and hydroponic structures offer potential for year round production and resource efficiency, their initial capital investment exceeds the financial capacity of most residents especially women, who spend 40–50% of their meager income on food. Without inclusive training or asset-based support, female-led gardens stay locked in subsistence mode, stifling their scalability.

4 Discussion

This study affirms vertical gardening's contribution to all four dimensions of food security: availability, accessibility, utilization, and stability. It enhances availability by allowing households to grow fresh, nutritious vegetables at home, reducing reliance on volatile market supplies and increasing confidence in food safety (Ndunge et al., 2018; Gallaher et al., 2013). It improves accessibility by placing produce within immediate reach, particularly benefiting low-income and female-headed households during disruptions such as droughts or political unrest (Ayuya, 2024; Swanepoel and Van Niekerk, 2021). This method minimizes reliance on external food suppliers, reducing logistical expenses and making fresh produce more affordable. Studies show that urban farming initiatives in Nairobi and other cities improve local food security by integrating agriculture into daily life, ensuring a stable supply of nutritious food (Karanja and Nyaboga, 2023). On *utilization*, vertical gardening supports improved dietary diversity and safer food preparation. Respondents noted that home-grown vegetables are consumed fresh and often shared with neighbors, reducing the risk of contamination and enhancing nutritional intake: "*We no longer have the burden of buying vegetables every now. We normally share these vegetables*" (KE IDI 01); "*When there are no vegetables in the market you can use the ones in your small garden*" (KE IDI 03). Additionally, vertical gardens allow for selective harvesting and immediate cooking, which supports nutrient retention and food safety. On *stability*, vertical gardening enables year-round cultivation, buffering households against seasonal shortages, inflation, and market unpredictability, and aligning with broader efforts to build sustainable urban food systems in Kenya (Mwangi and Wanjiku, 2024).

A cost benefit analysis of household vertical gardening model presents a low-cost, high-impact intervention with strong returns in food security, income generation, gender empowerment, and climate resilience. With annual costs ranging from KES 2,000–3,500 and potential benefits exceeding KES 24,000 per household, the model is

highly scalable and well-suited for resource-constrained urban and peri-urban settings (Annex 1).

In spite of its clear benefits, vertical gardening face structural constraints that undermine its long-term sustainability. Insecure land tenure remains one of the most pressing challenges in Kibera, where most residents do not own the plots they cultivate, rendering their gardens vulnerable to eviction or displacement. Several women reported paying informal rent to youth groups or having gardens destroyed due to land disputes or new construction projects. Such uncertainty discourages long-term investment in vertical systems, particularly in hydroponic units and multilevel sack gardens that require upfront capital and infrastructure.

A comparative analysis of vertical gardening in Kibera, Mathare and Mukuru informal settlements in Nairobi country reveals core similarities rooted in the realities of informal urban living. All three settlements face acute land scarcity, prompting residents to adopt vertical farming techniques such as sack gardens, hanging containers, and vertical towers as practical solutions for food production (Gallaher et al., 2015; Oyaro, 2024). These practices are largely community-driven, leveraging recycled materials and local knowledge to grow vegetables like spinach, kale, and amaranth.

Despite these shared foundations, the scale, visibility, and institutional support for vertical gardening vary significantly across the three settlements (Annex 2). Kibera leads in adoption and recognition, with strong backing from NGOs making it a hub for innovation and pilot projects (Gallaher et al., 2015). Mathare, while less formalized, has seen growing interest through grassroots initiatives like City Shamba, often linked to environmental activism and waste management (Oyaro, 2024). Mukuru, on the other hand, lags behind in vertical gardening uptake due to environmental challenges like flooding and industrial pollution, and limited targeted interventions (Masita, 2016). These differences highlight the need for context-specific approaches leveraging Kibera's scalability, Mathare's community networks, and Mukuru's potential for climate-adaptive designs (Rullander and Grünewald, 2020). While studies in Kibera and elsewhere underscore vertical gardening's local impact, scholars such as Battersby et al. (2015) and Swanepoel and Van Niekerk (2021) caution that urban agriculture alone cannot resolve structural food insecurity without institutional alignment. Urban farming initiatives must be situated within broader systems of land tenure, infrastructure, and gendered labor dynamics to avoid reinforcing existing inequalities. As highlighted in recent reviews, urban agriculture contributes positively to food availability and access, but its transformative potential depends on policy coherence, environmental safeguards, and inclusive governance frameworks (Marra, 2023; Mead et al., 2024). Thus, vertical gardening should be viewed not as a panacea, but as one adaptive strategy within a multi-pronged ecosystem of urban resilience and food justice.

A further comparative perspective further reinforces the significance of context in shaping urban agricultural outcomes. A comparison between Kibera and informal settlements in Cape Town reveals both convergence and divergence in how urban farming is practiced and supported. In both contexts, urban agriculture contributes positively to dietary diversity, especially among low-income households. However, its potential to fully address food insecurity remains constrained by systemic issues such as insecure land rights, limited infrastructure, and fragmented policy support (Swanepoel and Van Niekerk, 2021). What distinguishes Kibera is the community's high degree of innovation and adaptability. Residents have repurposed discarded materials such as tires, crates, and plastic containers to create multilevel gardening systems that optimize limited space. These grassroots solutions reflect a deep sense of urban resilience and resourcefulness that deserves formal recognition and institutional support (Michailidis and Lazaridou, 2020).

Water scarcity is another critical constraint in Kibera's informal settlements, where inconsistent and costly water supply significantly hampers the ability to maintain vertical gardens. Although a few better-resourced households and schools have adopted hydroponics to optimize water use, these technologies remain inaccessible to majority due to financial barriers. The lack of institutional support such as irrigation subsidies, seed distribution, and extension training further compounds these inequities (Ndunge et al., 2018; Swanepoel and Van Niekerk, 2021). Additionally, environmental concerns add another layer of vulnerability, as Antisari et al. (2021) highlight risks of contamination from heavy metals and polluted urban runoff, emphasizing the need for robust water safety protocols. While vertical gardening reduces dependence on external markets, its sustainability hinges on access to uncontaminated inputs and safe cultivation practices.

Comparative insights from Latin America and South Asia illustrate how urban agricultural models diverge by context. In Mexico City, Torres-Lima et al. (1994) document how chinampa farming resists urban commodification while safeguarding indigenous agro ecological knowledge. Conversely, in Mumbai, Patel et al. (2022) examine how vertical farming interacts with slum rehabilitation policies, often constraining land access and farmer autonomy. These parallels affirm the need for locally responsive governance structures that protect cultivation space and recognize informal farming as a legitimate urban function.

Emerging shifts in gender dynamics within households practicing vertical gardening particularly among younger or dual-income families reflect a reconfiguration of traditional roles, with men and women increasingly sharing cultivation responsibilities, a change driven by evolving economic and cultural norms; yet, despite this progress, gendered labor in vertical gardening remains both a site of resilience and inequality, as men often control income from surplus produce even when uninvolved in cultivation, thereby reinforcing women's economic dependency and limiting their capacity to scale operations (Cole and Mitchell, 2011; Njuki et al., 2022); The invisible yet indispensable role of women documented by Doss (2018) often goes unrecognized in urban food policy. While women lead cultivation efforts, their control over land, training, and income remains circumscribed. Quisumbing et al. (2021) reinforce that true empowerment lies in shifting decision-making power not just increasing participation.

Technological innovations offer promise but require inclusive delivery. Hydroponic systems, described by Orsini et al. (2023) and Odero (2023), provide space-efficient alternatives in land-constrained environments. Yet uptake in Kibera remains modest due to high initial costs and uneven technical support especially for women. Without targeted subsidies and gender-sensitive training, vertical gardening risks perpetuating existing inequalities.

The presence of non-governmental organizations (NGOs) and community organizations has made a tangible difference in areas they operate in. Households that received technical training, agricultural inputs, or organizational support reported higher yields and more

confidence in their gardening activities. In particular, female-led cooperatives supported by NGOs demonstrated more equitable governance models and higher income reinvestment rates. However, these programs remain limited in both scale and sustainability, often relying on short-term donor funding, and without strategic alignment with public policy, their long-term impact remains fragile (De Cock et al., 2013; Battersby et al., 2015).

Vertical gardening remains constrained by structural barriers and policy neglect that undermine its integration into urban food systems. Although informal farmers in Nairobi significantly contribute to the fresh vegetable supply, they are systematically excluded from urban planning, infrastructure development, and governance processes. Without supportive legislation, designated farming zones, or recognition from municipal authorities, vertical gardening is relegated to informal spaces and remains vulnerable to displacement. This challenge mirrors findings from Swanepoel and Van Niekerk (2021) in the Western Cape, South Africa, where urban agriculture improved dietary diversity but had limited impact on household food security due to insufficient institutional support. These insights highlight the need for vertical gardening to be embedded within robust food security strategies backed by consistent governance and infrastructure. The concept of slum food sovereignty reframes urban agriculture as a right rather than a necessity. Zeiderman (2024) argues that food production must serve not just biological needs, but community autonomy and ecological stewardship. In Kibera, vertical gardening is more than subsistence it is a quiet assertion of control over urban space and survival.

Strengthening institutional frameworks could provide the policy stability needed for long-term investment in vertical gardening. Embedding it within strategic planning blueprints such as Kenya's Vision 2030, the Urban Food Systems Framework, and municipal climate adaptation strategies would legitimize local practices and facilitate resource mobilization. Integrating urban agriculture into slum upgrading programs, for example, could improve access to water, waste management services, and secure cultivation spaces.

Further, multi-sectoral partnerships including public-private collaborations could enhance access to affordable inputs such as drought-resistant seeds and low-cost irrigation systems, while cooperatives could enable collective marketing of surplus produce. Gender-responsive interventions, including microfinance programs for women-led farming groups and tailored entrepreneurship training, would also promote more equitable benefit-sharing from surplus sales. Community-driven mechanisms such as youth engagement and digital knowledge-sharing platforms hold potential for amplifying outreach and impact.

5 Conclusion

Vertical gardening is more than an agricultural innovation it is a gendered, socio-political, and ecological practice rooted in urban resilience. Residents of Kibera and in particular, Women have transformed discarded materials and cramped spaces into lifelines of nutrition and dignity.

Beyond enhancing household nutrition, vertical gardening holds transformative potential for advancing gender equity and urban resilience. Unlocking this promise requires placing women's lived experiences, labor, and leadership at the heart of urban food system strategies. To move beyond mere inclusion, urban agriculture initiatives must be gender-transformative ensuring equitable access to training, land, water, and control over the economic returns from gardening. Municipal governments should integrate vertical gardening into slum upgrading plans by designating protected cultivation spaces, improving water infrastructure, and recognizing women's contributions as central to food systems. These efforts should align with Kenya's national priorities under SDG 2 (zero hunger) and SDG 5 (gender equality), reinforcing commitments to sustainable and inclusive development.

Yet for this promise to scale beyond survival, enabling conditions must shift. Many vertical gardening initiatives are anchored in NGO-dependent interventions, characterized by short-term funding, pilot-based support, and limited infrastructural commitments. Without consistent institutional backing, communities face disruptions in inputs, training, and land access once donor cycles end jeopardizing progress and reinforcing vulnerability. Again, the long-term sustainability of these efforts remains vulnerable to structural impediments, including insecure land tenure, unreliable water access, and limited institutional support. Without formal rights to the spaces they cultivate or designated farming zones, women risk losing access to their gardens. Failure to address these foundational constraints risks reinforcing, rather than alleviating, existing inequalities.

First, municipal planning must recognize and protect urban farming zones. Drawing lessons from Mumbai and Mexico City, Nairobi County should embed vertical gardening into zoning laws, slum upgrading policies, and public health agendas. Dedicated land tenure frameworks such as micro-leases for women-led collectives can prevent displacement and institutionalize cultivation rights. Similarly, governments and donors should introduce targeted subsidies for climate-resilient technologies including hydroponic kits, sack gardens, and vertical planters paired with extension services tailored to informal settlements. These programs should emphasize marketing, post-harvest value addition, and inclusive outreach that reflects intersectional identities, addressing barriers related to gender, age, disability, and displacement.

Second, improving water access is equally critical. Municipal investments in community-based irrigation systems, rainwater harvesting, and subsidized water inputs can stabilize garden productivity and reduce the physical and financial burdens placed on women. Additionally, addressing environmental hazards is non-negotiable. As emphasized by Antisari et al. (2021), contaminated water and soil pose real threats to food safety. Public investment in greywater filtration, community boreholes, and water testing can reduce health risks while improving yields.

Third, urban agriculture programs must go beyond inclusion to transformation. Quisumbing et al. (2021) urge a shift from seeing women as beneficiaries to decision-makers. This entails providing microfinance and cooperative formation support, ensuring women's access to training, equipment, and post-harvest technologies and centering women's labor in policy dialogue and investment frameworks. Local governments could support the formation of urban gardening cooperatives, which elevate women's agency in decision-making, income management, and market engagement particularly in contexts where men dominate sales channels despite limited involvement in cultivation. These cooperatives should be equipped with training in legal rights, financial literacy, and negotiation to challenge entrenched norms around economic control.

Lastly, vertical gardening should be championed as a tool of slum food sovereignty. As Zeiderman (2024) posits, food justice in informal

settlements must integrate autonomy, ecology, and collective care. By framing vertical gardening as a rights-based intervention, city planners and donors can align programming with Kenya's Vision 2030, SDG 2 (Zero Hunger), and SDG 5 (gender equality).

While this study employed a robust multi-method qualitative approach, including IDIs, FGDs, and KIIs, its reliance on purposive sampling in only three sub-villages (Lindi, Makina, and Laini Saba) limits its representativeness. Future research should adopt comparative multi-settlement designs and mixed-method approaches to capture a broader spectrum of urban agricultural practices and deepen the analytical lens on gendered dynamics in food systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by National Council of Science, Technology, and Innovation (NACOSTI), Kenya (NACOSTI/P/23/31984). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

JO: Validation, Resources, Project administration, Writing – review & editing, Formal analysis, Software, Conceptualization, Methodology, Writing – original draft, Data curation, Supervision, Visualization, Investigation. DO: Conceptualization, Validation, Methodology, Supervision, Writing – review & editing. DA: Validation, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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